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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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☐ *Additional inventors are being named on the ____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

COMPACT COLOUR MIXING AND COLLIMATING OPTICS FOR A MULTI-CHIP LIGHTING MODULE

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Respectfully submitted,

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COMPACT COLOUR MIXING AND COLLIMATING OPTICS FOR A MULTI-CHIP LIGHTING MODULE

FIELD OF THE INVENTION

The present invention pertains to an integral optical design for luminaires and in particular to efficient light extraction, colour mixing and collimation of light emitted by a dense arrangement of white or colour light-emitting devices.

BACKGROUND

Present optical designs do not optimally address compactness or integration of LED based luminaires. Today's solutions utilize single colour LED packages and typically only provide primary optics to which secondary or optional tertiary optical systems have to be added to meet the functional requirements. This modular method leads to difficulties in beam collimation, colour mixing and efficiency that can only be overcome with bulky additions making the overall optical design complicated and costly.

Only a few multi-colour solutions exist that integrate more than one LED in a single package, for example, ENLUX or Seoul semiconductor packages. However, these solutions do not effectively address beam collimation or colour mixing and cannot provide a satisfactory solution in one single component. The technical challenge is to achieve sufficient colour mixing and beam collimation at high efficiency.

Most LED manufacturers supply components that incorporate one LED die which is encapsulated and provided with a simple primary optic of very limited utility for lighting purposes. Only some manufacturers supply multi-colour LED packages but none of these packages attempt to maximize light extraction efficiency as this can potentially result in compromise on the thermal performance of the package.

Both, United States Patent No. 6,200,002 and U. S. Patent No. 6,547,416 address optical designs for effective colour mixing to generate a light beam having chromaticity and

illuminance cross sectional profiles of sufficient homogeneity. However, neither addresses issues of packaging density. In consequence, these designs can only generate light beams which have inferior brightness and additionally require optical systems with considerably bigger dimensions.

Therefore there is a need for a new compact multi-chip lighting module with colour mixing and collimating optics.

This background information is provided to reveal information believed by the applicant to be of possible relevance to the present invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a compact colour mixing and collimating optics for a multi-chip lighting module. In accordance with an aspect of the present invention, there is provided a luminaire module comprising: a plurality of light-emitting elements for generating light having one or more colours, said light-emitting elements positioned into a closely packed array; a primary optical system in optical communication with the plurality of light-emitting elements, said primary optical system providing a means for light extraction from the plurality of light-emitting elements; and a secondary optical system in optical communication with the primary optical system, said secondary optical system for mixing and collimating the light extracted from the light-emitting elements.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1A illustrates a light-emitting element configuration comprising one red, two green, and one blue LED aligned on a substrate according to one embodiment of the present invention.

Figure 1B illustrates a light-emitting element configuration comprising one red, one green, one blue, and one amber LED aligned on a substrate according to another embodiment of the present invention.

Figure 1C illustrates a light-emitting element configuration comprising four white LEDs aligned on a substrate according to a further embodiment of the present invention.

Figure 1D illustrates a light-emitting element configuration comprising two red, three green, one blue, and one amber LED aligned on a substrate according to another embodiment of the present invention.

Figure 1E illustrates a light-emitting element configuration comprising one green, and one blue LED, and six white LEDs aligned on a substrate according to another embodiment of the present invention.

Figure 2A illustrates an elevated cross sectional view of a primary optical system of a luminaire module according to one embodiment of the present invention.

Figure 2B illustrates an elevated cross sectional view of another primary optical system of a luminaire module according to one embodiment of the present invention.

Figure 2C illustrates an elevated cross sectional view of another primary optical system of a luminaire module comprising according to one embodiment of the present invention.

Figure 2D illustrates an elevated cross sectional view of a primary optical system of a luminaire comprising according to one embodiment of the present invention.

Figure 2E illustrates an elevated cross sectional view of a primary optical system of a luminaire module according to one embodiment of the present invention.

Figure 2F illustrates an elevated cross sectional view of a primary optical system of a luminaire module according to one embodiment of the present invention.

Figure 2G illustrates an elevated cross sectional view of part of a carrier and an attached luminaire module according to one embodiment of the present invention.

Figure 3A illustrates a circular, a triangular, a square, a hexagonal, and an octagonal shape of a perpendicular cross section of a light-pipe or light-guide acting as a secondary optical system according to one embodiment of the present invention.

Figure 3B illustrates elevated cross sectional views of secondary optical systems according to one embodiment of the present invention.

Figure 3C illustrates elevated cross sectional views of secondary optical systems according to another embodiment of the present invention

Figure 4A illustrates an elevated side view of two luminaire modules, each having a separate primary and a secondary optical system according to one embodiment of the present invention

Figure 4B illustrates an elevated side view of a system comprising two individual primary optical systems and two individual secondary optical systems integrated into one element and a common tertiary optical system according to one embodiment of the present invention.

Figure 4C illustrates an elevated cross sectional view of a system comprising two individual primary optical systems and a common single integrally formed body providing a secondary optical system according to one embodiment of the present invention.

Figure 5A illustrates an elevated cross sectional view of a luminaire module according to an embodiment of the present invention according to one embodiment of the present invention.

Figure 5B illustrates a perpendicular cross section of the luminaire module as illustrated in Figure 5A having a substantially circular shape.

Figure 5C illustrates a perpendicular cross section of the luminaire module as illustrated in Figure 5A having a substantially square shape.

Figure 6A illustrates an elevated cross sectional view of a luminaire module according to another embodiment of the present invention according to one embodiment of the present invention.

Figure 6B illustrates a perpendicular cross sections through the secondary optical system as illustrated in Figure 6A having a circular shape.

Figure 6C illustrates a perpendicular cross sections through the secondary optical system as illustrated in Figure 6A having a hexagonal shape.

Figure 7A illustrates an elevated view of a luminaire module according to an embodiment of the present invention in which the secondary optical system of the luminaire module comprises a multi-functional solid refractive element according to one embodiment of the present invention.

Figure 7B illustrates the perpendicular cross section of the embodiment illustrated in Figure 7A.

Figure 8 illustrates an elevated cross sectional view of a luminaire module according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

The term "light-emitting element" is used to define any device that emits radiation in a particular region or combination of regions of the electromagnetic spectrum for example the visible region, infrared or ultraviolet region, when activated, by applying a potential difference across it or passing a current through it, for example. Examples of light-emitting elements include solid-state semiconductor, polymer or organic light-emitting diodes, LEDs, PLEDs or OLEDs respectively, or other similar devices as would be readily understood.

The term "chromaticity" is used to define the perceived colour impression of light as it is perceived by a human observer according to standards of the Commission Internationale de l'Eclairage.

The term "luminous flux output" is used to define the quantity of luminous flux emitted by a light source according to standards of the Commission Internationale de l'Eclairage.

The term "luminous intensity" is used to define the quantity luminous flux per unit solid angle emitted by a light source according to standards of the Commission Internationale de l'Eclairage and is typically measured in candela.

The term "luminance" is used to define quantity of luminous flux per unit solid angle and unit area of a light source as it is perceived by a human observer according to standards of the Commission Internationale de l'Eclairage and is typically measured in lumen/steradian/cm^2.

The term "gamut" is used to define the plurality of chromaticity values that a light source can achieve.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

The present invention provides a compact format luminaire module that can provide a desired level of mixing and collimating of light generated by multiple light-emitting element chips within the luminaire module. The luminaire module comprises a plurality of light-emitting elements for generating light having one or more colours, wherein the light-emitting elements are configured into a closely packed array. The module further comprises a primary optical system enabling light extraction from the light-emitting elements to which it is optically coupled. A secondary optical system that is optically coupled to the primary optical system is additionally integrated into the luminaire module. The secondary optical system is configured to be compatible with the primary optical system and provides a means for mixing and collimating the light extracted from the plurality of light-emitting elements. Furthermore the primary optical system may be integral to the secondary optical system. The luminaire module may further comprise a tertiary optical system to further manipulate the light after interaction with the secondary optical system.

The optical design of the present invention can be utilized in luminaries to effectively generate adjustable white or colour light with high optical efficiency. Moreover, the optical design utilizes a combination of different white or colour light-emitting elements in a highly effective compact luminaire module design. The luminaire module can comprise light-emitting

elements which can emit light in different wavelength regimes. Examples for wavelength regimes are red, green, blue, or amber or other desired wavelength regimes as would be readily understood. The luminaire module design enables colour mixing and beam collimation. The light-emitting elements in the luminaire module can be dimmed such that the luminaire module can generate light of independently controllable chromaticity and luminous flux output. The chromaticity of the luminaire module can be controlled to generate white light within a predetermined range of correlated colour temperatures (CCT) or it can be controlled to generate any colour within the gamut of the luminaire module.

The luminaire module can provide effective and efficient light extraction, colour mixing, beam shaping and collimation in an integral design. It takes into account the module geometry, the placement of the light-emitting elements, and the integration of the optical components.

Positioning of Light-Emitting Elements

The luminaire module design utilizes closely packaged light-emitting elements, for example, densely mounted LED dies on a substrate. High density light-emitting elements can provide high luminance which can greatly simplify the optical design. The luminaire module, and in consequence, the luminaire, can be more compact and require fewer and smaller optical components. Moreover, light originating from densely packed different colour sources can be more easily mixed into a light beam of a desired homogeneous chromaticity. The optical system of the luminaire module can serve as a housing to encapsulate the light-emitting elements and protect them from environmental conditions. In one embodiment, an additional tertiary optical system can provide further beam conditioning.

The luminaire can comprise one or more light-emitting elements. The relative placement of the light-emitting elements and the optical system is important and can strongly affect the effectiveness and efficiency of the luminaire. Closely arranging the light-emitting elements can improve mixing and reduce losses of the emitted light but can also increase thermal stress which may require an additional thermal management system.

In one embodiment, one or more red, green, and blue, or red, green, blue, and amber light-emitting elements can be arranged in a two-dimensional lattice, for example, in a square, circular, hexagonal lattice, or it can be arranged in any other regular, pseudo-regular, or irregular fashion on surfaces of any shape. For example, the specific arrangement of light-emitting elements can maximize luminance by reduction of spacing between the light-emitting elements. Furthermore specific arrangement can ensure that the individual colours are evenly distributed such that a homogeneous chromaticity and illuminance of a plane illuminated by the luminaire module is achievable. For example, it can be beneficial for achieving a homogeneous chromaticity, when the arrangement of light-emitting elements for each colour has zero total colour momentum relative to the optical axis in axial symmetrical optical systems. The colour momentum of a light source is the product of its chromaticity and its distance relative to the origin of a chosen coordinate system, and the total colour momentum is the sum of these products over all light-emitting elements of the same colour. A luminance momentum can be equally defined. Either momentum can be important in quantifying the homogeneity of the light beam of the luminaire.

Figures 1A, 1B and 1C illustrate light-emitting element configurations according to embodiments of the present invention. Figure 1A illustrates an alignment of one red LED, two green LEDs, and one blue LED as it can be affixed on a substrate. Figure 1B illustrates an alignment of one red, one green, one blue, and one amber LED as it can be affixed on a substrate. Figure 1C illustrates and alignment of four white LEDs as it can be affixed on a substrate. Figure 1D illustrates an alignment of two red and three green LEDs, and one blue and one amber LED as it can be affixed on a substrate. Figure 1E illustrates and alignment of one green, and one blue LED, and six white LEDs as it can be affixed on a substrate. The dashed line **111**, **121**, **131**, **141** and **151** indicate the size and substantially square, circular, square, octagonal and hexagonal cross section, respectively of the entrance aperture of the corresponding optical system. It is understood that the optical design of the luminaire can have any other arrangement of any other number of colour or white light-emitting elements.

Primary Optical System

The luminaire module comprises a primary optical system enabling light extraction from the light-emitting elements to which it is optically coupled. The primary optical system can

include one or more refractive elements, for example, a dome lens per one or more light-emitting elements, or a micro-lens array having one lenticular element per each or more light-emitting elements or a micro-lens array having more than 1 lenticular element for each light-emitting element. The refractive element can be a solid glass or plastic or a fluid optical element. Furthermore the primary optical system can also comprise one or more diffractive or holographic elements, or one or more diffusive or specular reflective elements.

In one embodiment the primary optical system can comprise an index matching encapsulation material. To improve light extraction, the light-emitting elements can be encapsulated in a transparent material with a predetermined optical refractive index. For example, the transparent material can have a refractive index of 1.4 to 2. The optical refractive index of the material can be chosen to match the index of refraction of, for example, the LED dies. Alternatively the encapsulation can have a predetermined thickness and optical refractive index to increase light extraction. The surface of the die can be coated with encapsulation material with a layer of determined thickness and optical refractive index creating anti-reflective coating comparable to anti-reflective coatings used in optics manufacturing.

In one embodiment the encapsulation material can be patterned or textured, for example, sanded, embossed, stamped, or otherwise structured or microstructured. In one embodiment the encapsulation material may be shaped like a dome lens or a microlen sarray by a stamping method thereby eliminating the need for a glass or plastic lens serving the same function.

Figures 2A, 2B, 2C, 2D, 2E, 2F and 2G illustrate elevated cross sections of primary optical system according to embodiments of the present invention. Figure 2A illustrates an elevated cross sectional view of a primary optical system of a luminaire module comprising a dome lens **311** optically communicating with two or more light-emitting elements **313**. Figure 2B illustrates an elevated cross sectional view of a primary optical system of a luminaire module comprising one dome lens **321** for each of one or more light-emitting elements. Figure 2C illustrates an elevated cross sectional view of a primary optical system of a luminaire module comprising a micro lens array **331** optically communicating with two or more light-emitting elements. Figure 2D illustrates an elevated cross sectional view of a primary optical system of a luminaire comprising a dome lens optically communicating with two or more light-emitting elements which can have a lateral reflector element **345** circumscribing the light-emitting

elements. Figure 2E illustrates an elevated cross sectional view of a primary optical system of a luminaire module comprising an optical encapsulating material having a textured or embossed surface or interface **357**. The encapsulation material may be a material with high refractive index and can be embossed or textured by ways well known to someone skilled in the art. Figure 2F illustrates an elevated cross sectional view of a primary optical system of a luminaire module comprising a fluid lens **361** with controllable focal length. The fluid lens can be made of, for example, one or more electro active materials which can be designed to adapt their shape according to an applied electrical field. For example, the focal length can be controlled by applying a voltage to one or more electrodes **369** positioned within the primary optical system. The one or more electrodes can be connected to a controller which can apply and control the voltage between them to create a required electrical field under which the one or more electro active materials shape to form a refractive optical element of adjustable focal length. It is understood that a variable focal length lens can be achieved by utilizing material that changes its refractive index within an electrical field such as a liquid crystal material thereby achieving variable focal length due to refractive index changes within the material instead of a change in shape. Figure 2G illustrates an elevated cross sectional view of part of a carrier **372** and an attached luminaire module **370**. The assembly comprises one or more light-emitting elements **373** mounted to a substrate **374**, encapsulated by refractive index matching material **376**, covered by a dome lens **371** and surrounded by an insert **378**. The insert can have a reflective surface facing the light-emitting elements. In addition, the insert can mechanically attach the luminaire module to a carrier.

It is understood, that each of the modules as illustrated in Figures 2A to 2G can comprise encapsulation material which can be optically active.

In one embodiment of the present invention, the primary optical system can comprise a light pipe system which can be optimally coupled to the encapsulation material.

In one embodiment of the present invention, the primary optical system is integrated into the secondary optical system.

Secondary Optical System

The luminaire module further comprises a secondary optical system. The secondary and the primary optical system can be coupled to minimize light loss between the two systems. The secondary optical system can provide colour mixing functionality, which can be required in luminaires with multi-colour light-emitting elements. The secondary optical system can generate a light beam of substantially homogeneous chromaticity and luminance which is suitable for illuminating objects at a predetermined distance with light of a predetermined chromaticity or CCT. In addition, the secondary optical system can facilitate beam shaping and can collimate the light beam into a predetermined solid or conical angle, for example, for spotlight applications having a luminous intensity profile of 20° FWHM (full width at half maximum).

The secondary optical system can comprise one or more reflective or refractive optical elements, for example, solid or hollow light pipes or light guides for the transmission of light. The optical elements can have predetermined axial or perpendicular cross sections. The secondary optical system can comprise refractive elements, for example, one ore more lenses, Fresnel lenses, lens arrays, tandem lens arrays, diffractive and holographic elements. It can also comprise diffuser elements or fluid lenses with variable focal lengths to control beam distribution and collimation. In one embodiment the secondary optical system comprises a hollow or solid lightpipe. This secondary optical system can be designed to minimize the number of times light is reflected when transmitted through this optical system and still provide mixing or randomization of light to provide homogeneous chromaticity and luminance. It is understood, that each reflection reduces the light intensity by a reflectivity factor R and therefore after N reflections with the same reflectivity factor R the total reflected intensity I_N can be expressed in terms of the original intensity I_0 and can be evaluated based on the following:

$$I_N = I_0 \cdot R^N \tag{1}$$

The secondary optical system can have a reflective wall surface of predetermined perpendicular and axial cross sectional profile that extends between an entrance aperture and an exit aperture. The wall surface can assist with beam shaping and colour mixing. It is

understood, that the cross section of the surface can have an axial symmetric shape or it can have any other desired shape. The surface can flare or taper towards the exit aperture. For example, axially symmetrical systems with square, hexagonal or octagonal perpendicular cross sections can more effectively mix and randomize light than circular or triangular wall structures. Consequently, this form of secondary optical system can provide better randomization can have more compact dimensions.

It is understood, that the cross sectional shape of, for example, an axially symmetric light pipe can determine the collimation properties of a beam. For example, the length and flare angle of a light pipe can optimize the efficiency of the luminaire. Generally, the shape of the reflective wall, for example, its axial profile for an axial symmetric reflective wall, can determine the effectiveness of the secondary luminaire system. For example, the profile can be characterized by its entrance aperture size, exit aperture size, length, and curvature.

In one embodiment the curvature of the profile can be parabolic, elliptic, or hyperbolic. Alternatively, the profile or the optically active surface can comprise individual straight or curved continuous conical segments.

It is also understood that a part or all of the wall surface, entrance aperture or exit aperture can be optically active. For example they can be coated in a phosphor.

In one embodiment, the secondary optical system can comprise a refractive element, for example, a dome lens, a Fresnel lens, or a micro lens array proximal to the output aperture. This element can be an integral part of one of the aforementioned light pipe or light guides, for example. It is understood, that the secondary optical system can also comprise a diffractive, a holographic, a reflective, or a diffusive element proximal to the exit aperture. Furthermore, any refractive element can also be a controllable variable focal length fluid lens.

In addition, the optical system can be designed to leak or guide a small amount of the luminous flux output to one or more photosensitive elements or one or more extraction elements with one or more attached photosensitive elements. The photosensitive elements can provide information relating to chromaticity or luminous flux output to a control system.

For example, these photosensitive elements can be a photo-sensor, photo-diode or other optically sensitive sensor as would be known by a worker skilled in the art.

Figures 3A, 3B and 3C illustrate various cross sectional shapes of secondary optical systems according to embodiments of the present invention. Figure 3A illustrates various embodiments having a circular, a triangular, a square, a hexagonal, and an octagonal cross section perpendicular to the overall light propagation of a secondary optical system, for example, a light-pipe or light-guide. In one embodiment, optical elements of square, hexagonal, or octagonal perpendicular cross section are used because they can more effectively mix light than optical elements of circular or triangular perpendicular cross section. Figures 3B and 3C illustrate four cross sectional views **210, 220, 230, 240** of luminaire modules each having different cross sections according to the present invention. Each luminaire module comprises a number of light-emitting elements **211** affixed on a substrate **213** and a secondary optical element **215**, for example, an axial symmetric hollow body with a mirrored inside surface extending from the light-emitting elements. Figure 3B illustrates a cylindrical hollow body **215** and a concave axial symmetrical hollow body **225**. Figure 3C illustrates a conical hollow body **235** and a polygonal hollow body 245 with the polygon cross section being created by joining of linear segments.

Tertiary Optical System

Following the optical path, the luminaire module may comprise a further tertiary optical system in addition to the primary and secondary optical system. It is understood, that the tertiary optical system can be designed to further improve beam shaping of one or more luminaire modules or adjust beam shaping of the luminaire module to the required application. In contrast, each of the primary and secondary optical systems are optically active at a luminaire module level. The tertiary optical system can comprise any combination of aforementioned optical elements and can be used to manipulate light emitted from one or more luminaire modules.

EXAMPLES

Figures 4A and 4B illustrate embodiments of a luminaire module according to embodiments of the present invention. Figure 4A illustrates an elevated side view of two luminaire modules **410**, each having individual primary **411** and secondary optical systems but can share a single tertiary optical system, which is not illustrated. The optical system comprises an optical feed back sensor **419**, for example, a photo diode positioned in the center between the luminaire modules. Figure 4B illustrates an elevated cross sectional view of a system comprising two separate primary optical systems **421** having one common integrally formed body **422** providing a common secondary optical system. The integrally formed body can allow optical communication within the secondary optical system **422**. A tertiary optical system **423** is provided to further manipulate the light emitting from the light modules. An optical feedback sensor can be placed between the two modules 421 and provisions can be made to guide a small portion of light representative of chromaticity and luminous flux output of the system to the sensor. The integrally formed body can contain two or more arrangement modules, for example six modules in an hexagonal arrangement.

Figure 4C illustrates an elevated cross sectional view of part of a luminaire system in which the single integrally formed body comprises a secondary optical system **432** which optically couples two primary optical systems, according to one embodiment of the present invention. The luminaire system comprises an optical feed back sensor **439** positioned between the primary optical systems and in optical communication with the secondary optical system. The interface **433** of the secondary optical system on the far side of the light-emitting elements can be shaped to any form required to assist in refractive beam shaping, and it can be textured, embossed or otherwise structured to provide, for example, a Fresnel lens. The interface **434** of the secondary optical system on the near side of the optical feed back sensor can be shaped to any form to assist in the extraction of light from the primary optics in the sections in proximity to the light emitting elements, to assist in the shaping of the output beam and can be coated and shaped to assist in the extraction of an amount of light from the secondary optical system which is representative of the total light emitted by the luminaire system and sufficient for reliable operation of the sensor element. This interface can additionally be textured or

otherwise structured. The surfaces or interfaces can be structured by means well known to someone skilled in the art.

Figure 5A illustrates an elevated cross sectional view of a luminaire module **500** according to an embodiment of the present invention. The luminaire module comprises four light-emitting elements **503**, for example, one red and one blue, and two green or one of each of red, green, amber, and blue colour, which are affixed to a substrate **510**. The light-emitting elements are encapsulated by a refractive index matching material **520**, for example, high refractive index silicone. The light-emitting elements are environmentally sealed by the substrate and the primary optical system. In addition, the primary optical system comprises a dome lens **525**. The luminaire module comprises a secondary optical system which has a mirror element **530** with a specular or diffuse reflective inner surface **531** extending from an entrance aperture **540** which widens into an exit aperture **545**. The secondary optical system additionally comprises a refractive optical element **550**, for example, a planar-convex or any other lens, positioned proximal to the exit aperture of the mirror element. In addition, a diffuser element, which is not illustrated, can be positioned after the refractive optical element following the optical path. Figure 5B illustrates a perpendicular cross section of the luminaire module in which the mirror element has a substantially circular shape. Alternatively, Figure 5C illustrates a perpendicular cross section of the luminaire module in which the mirror element has a substantially square shape. The dimensions of the optical system can be compact, for example, 30mm tall by 20 mm across or in diameter.

One or more luminaire modules having white or colour light-emitting elements can be operatively attached to a carrier to form a complete luminaire and electrically connected to a controller controlling the chromaticity and luminance of the luminaire through adjustment of the light output of the light-emitting elements.

Figure 6A illustrates an elevated cross sectional view of a luminaire module according to another embodiment of the present invention. The luminaire module comprises a primary **610** and a secondary **620** optical system similar to the embodiment illustrated in Figure 5A. The light-emitting elements are encapsulated by a refractive index matching material, for example, high refractive index silicone. It additionally comprises a substrate **630** which is positioned inferior to a carrier **640** on the far side of carrier opposite the secondary optical system. The

substrate can provide a thermal interface **631** on the far side opposite to the side of the substrate to which the light-emitting elements **601** are affixed. The thermal interface can be thermally connected to a thermal management system which is not illustrated. The luminaire module further comprises an insert **650** having a reflective surface facing the light-emitting modules. Figures 6B and 6C illustrate perpendicular cross sections of embodiments as illustrated in Figure 6A of a secondary optical system having a respective circular and hexagonal shape.

Figure 7A illustrates an elevated view of a luminaire module according to an embodiment of the present invention in which the secondary optical system **720** of the luminaire module comprises a multi-functional solid refractive element **730**. The exit aperture of the refractive element has a macro-structured surface **731** circumscribed by a circumferential surface **732** of, for example, octagonal perpendicular cross section. The refractive element can be designed to provide any desired refractive functionality. It can also have a micro-structured surface that provides, for example, a translucent diffusive character. The input aperture of the solid refractive element can be flat or can be shaped like a negative dome or microlens array for example. Insertion of encapsulation material with high refractive index into the cavity between LED die and input aperture of the optic can lead to high extraction efficiency and a reduced number of parts. A solid optic can comprise a shaped output aperture as indicated and a shaped input aperture (also indicated in figure 7A) reducing the number of required parts to one optic only in comparison to a hollow optic system. The solid refractive element 730 can be made such that the rays propagate by Total Internal Reflection or the wall surfaces can be coated such that high reflectivity is achieved.

The circumferential surface **732** can be specular or diffuse reflective, for example, the surface can be coated with reflective material or its surface can be structured or textured. Figure 7B illustrates a top view of a luminaire having an octagonal cross section according to an embodiment as illustrated in Figure 7A.

It is understood, that a luminaire module can have any other perpendicular cross section. It is also understood, that the refractive element and any other optical system component can be affixed to for example the substrate or the carrier or a tertiary optical system, via any affixing technology known in the art, which can secure the optical system components in a position

relative to the light-emitting elements which is required for the effective extraction of light emitted by the light-emitting elements.

Figure 8 illustrates an elevated cross sectional view of a luminaire module according to another embodiment of the present invention. The luminaire module comprises a secondary optical system comprising a reflective element **830** having convex shaped inner reflective surface **831** extending between an entrance and an exit aperture. A Fresnel lens **840** covers the exit aperture which can improve beam collimation under operating conditions. A number of light-emitting elements **801** affixed to a substrate **810** are covered by a refractive index matching material **820** which is covered by a micro lens array element **825** which extends into the entrance aperture. The substrate is affixed to the top of a carrier **870**. It is understood, that the inner surface can be specular or diffuse reflective and that its shape can have any form required for effective colour.

It is further understood, that the reflective element **830** can be a hollow body having a reflective inner surface.

It is obvious that the foregoing embodiments of the invention are exemplary and can be varied in many ways. Such present or future variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

I CLAIM:

1. A luminaire module comprising:
   a) a plurality of light-emitting elements for generating light having one or more colours, said light-emitting elements positioned into a closely packed array;
   b) a primary optical system in optical communication with the plurality of light-emitting elements, said primary optical system providing a means for light extraction from the plurality of light-emitting elements; and
   c) a secondary optical system in optical communication with the primary optical system, said secondary optical system for mixing and collimating the light extracted from the light-emitting elements.

ABSTRACT

The present invention provides a compact format luminaire module that can provide a desired level of mixing and collimating of light generated by multiple light-emitting element chips within the luminaire module. The luminaire module comprises a plurality of light-emitting elements for generating light having one or more colours, wherein the light-emitting elements are configured into a closely packed array. The module further comprises a primary optical system enabling light extraction from the light-emitting elements to which it is optically coupled. A secondary optical system that is optically coupled to the primary optical system is additionally integrated into the luminaire module. The secondary optical system is configured to be compatible with the primary optical system and provides a means for mixing and collimating the light extracted from the plurality of light-emitting elements. Furthermore the primary optical system may be integral to the secondary optical system. The luminaire module may further comprise a tertiary optical system to further manipulate the light after interaction with the secondary optical system.

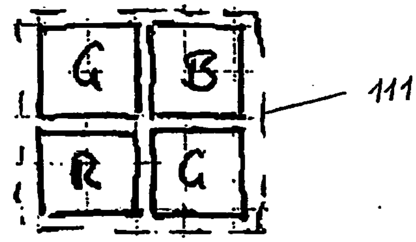

FIGURE 1A

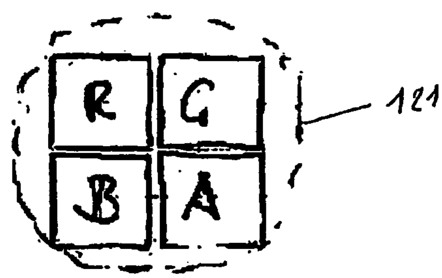

FIGURE 1B

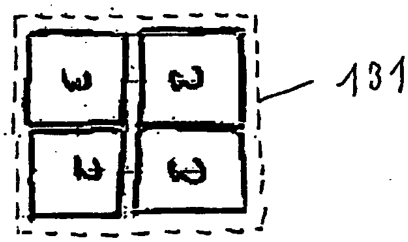

FIGURE 1C

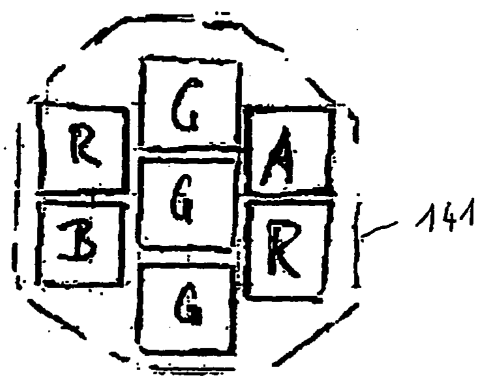

FIGURE 1D

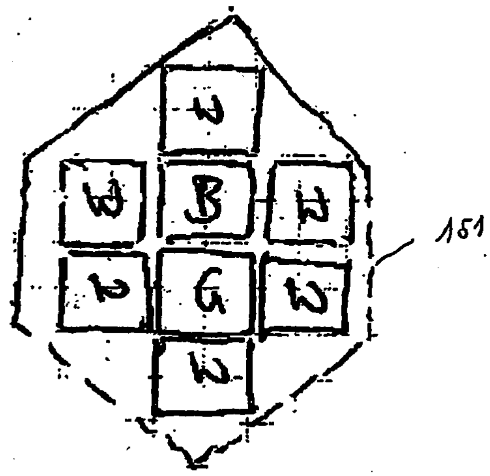

FIGURE 1E

FIGURE 2A

FIGURE 2B

FIGURE 2C

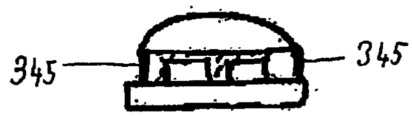

FIGURE 2D

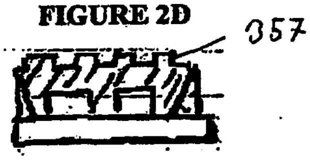

FIGURE 2E

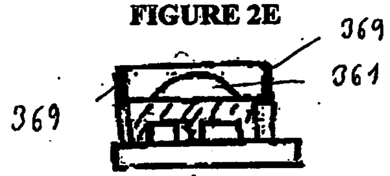

FIGURE 2F

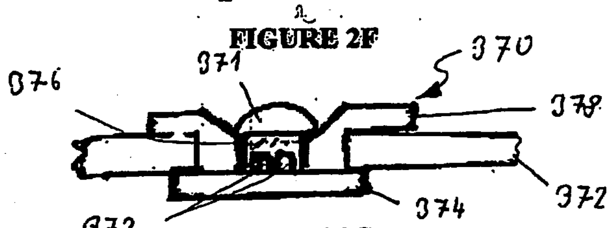

FIGURE 2G

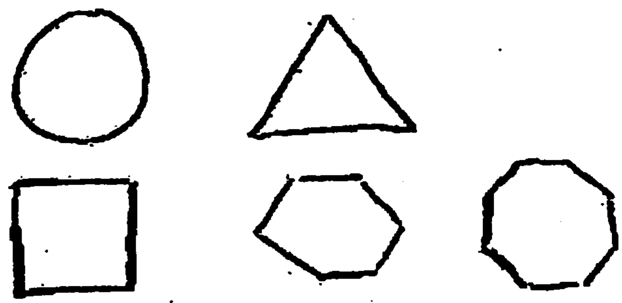

FIGURE 3A

FIGURE 3B

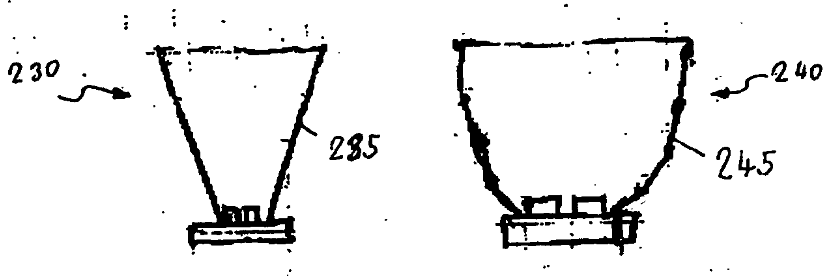

FIGURE 3C

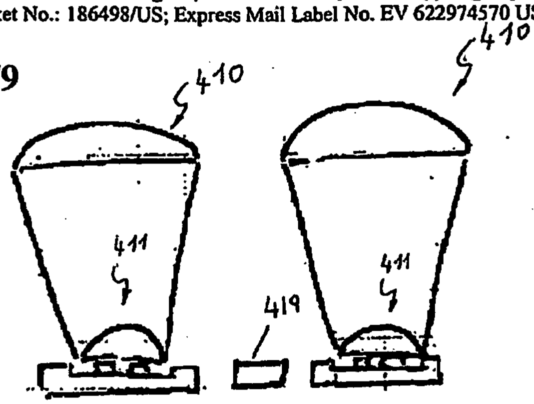

FIGURE 4A

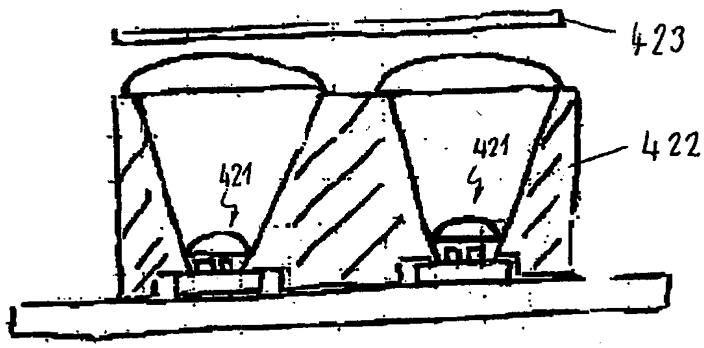

FIGURE 4B

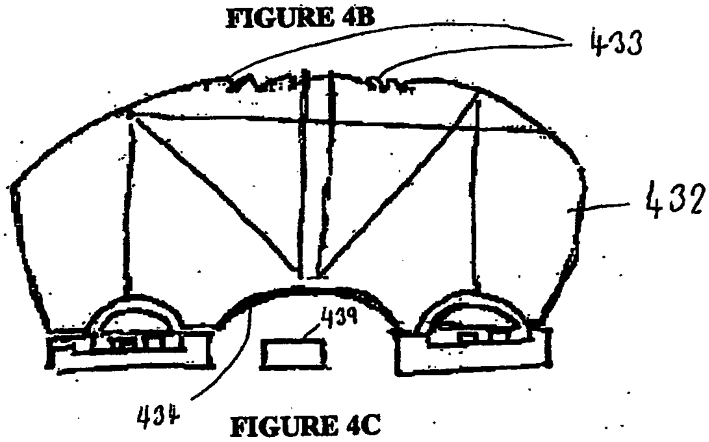

FIGURE 4C

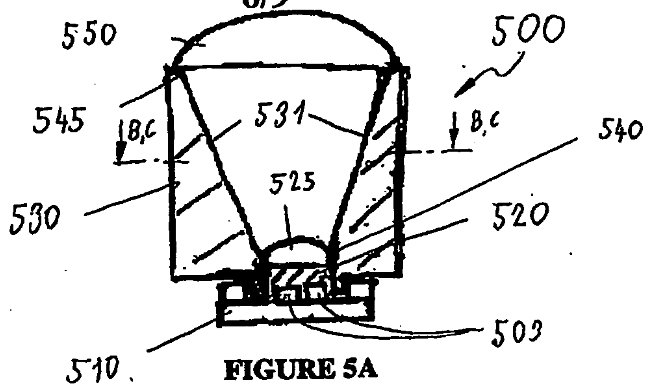

FIGURE 5A

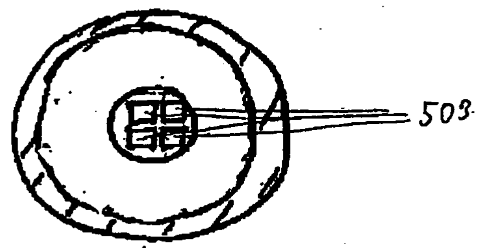

FIGURE 5B

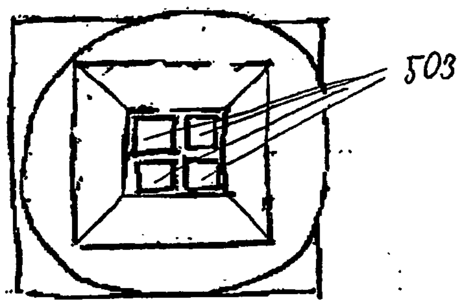

FIGURE 5C

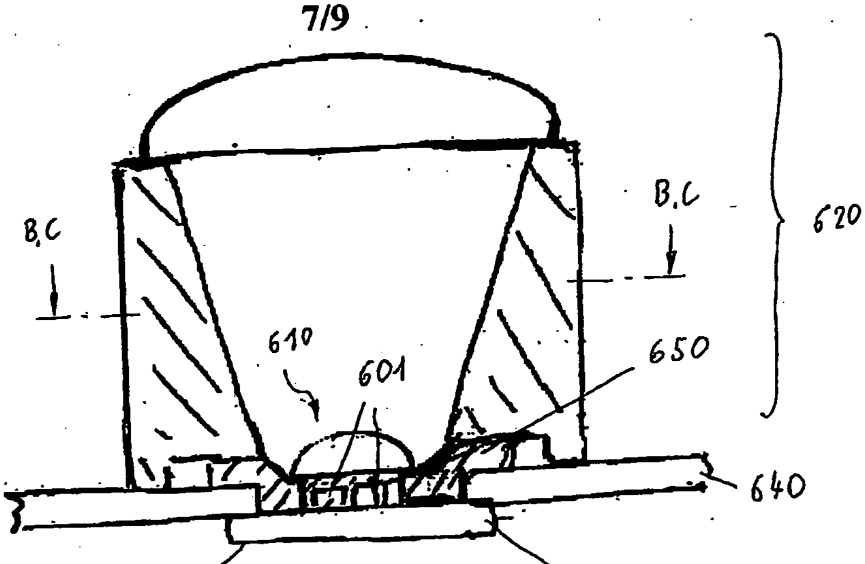

FIGURE 6A

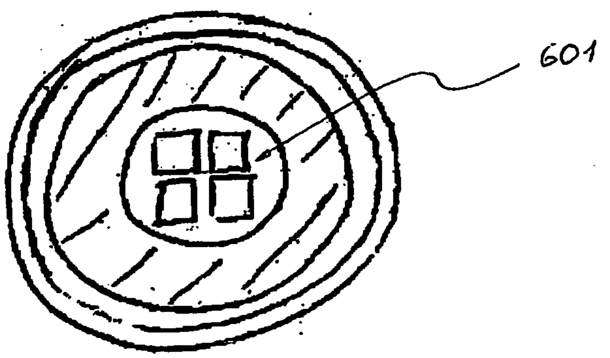

FIGURE 6B

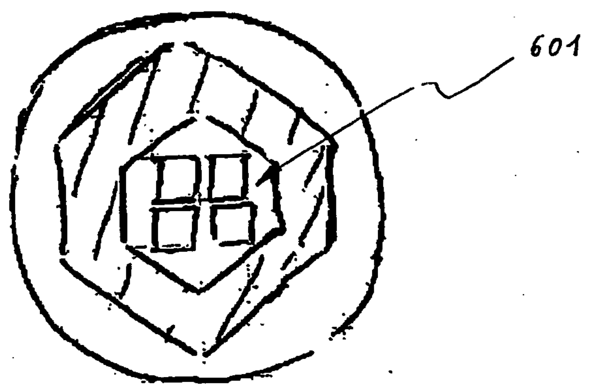

FIGURE 6C

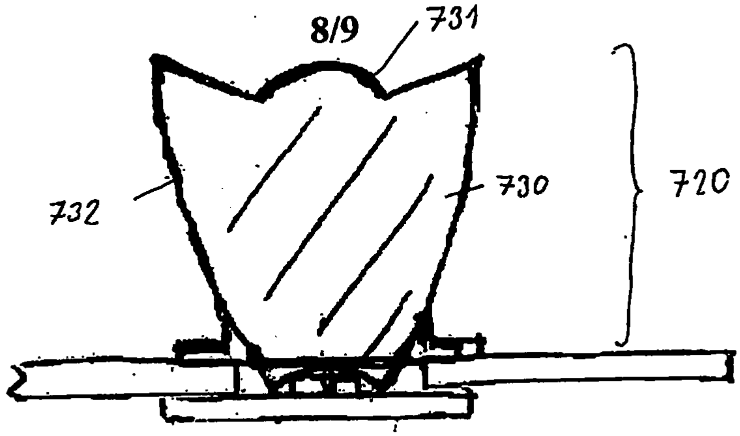

FIGURE 7A

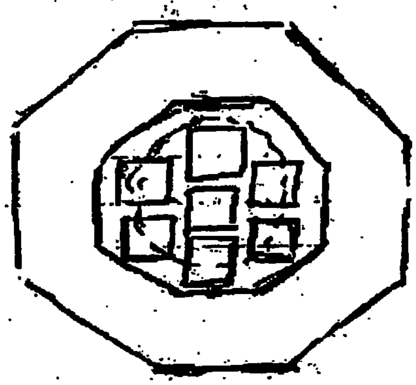

FIGURE 7B

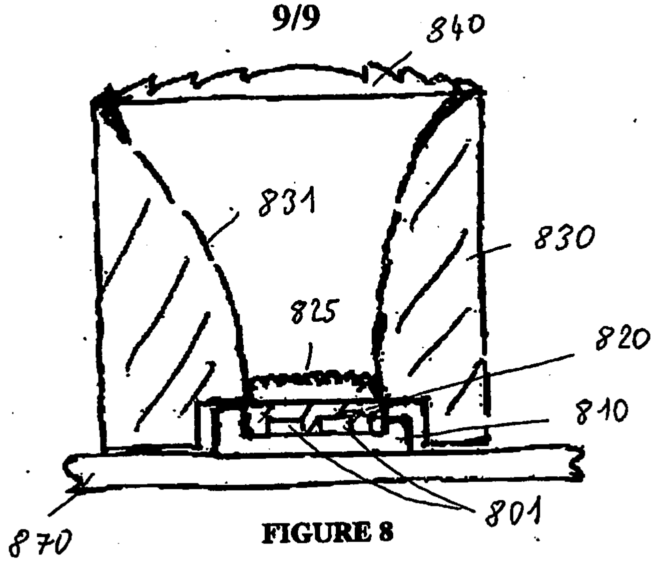

FIGURE 8